Eastern
No. 176
Confidential



# EASTERN ADEN PROTECTORATE

# (HADHRAMAUT)

# WATER PROBLEMS

---

Report by

A. Beeby Thompson & Partners

May 1939

Eastern
No. 176
Confidential

# EASTERN ADEN PROTECTORATE

# (HADHRAMAUT)

# WATER PROBLEMS

---

Report by

A. Beeby Thompson & Partners

May 1939

# C O N T E N T S

## SUMMARY OF CONTENTS

Attention is drawn to ways and means of extending or improving the cultivation in a large number of districts where limitations have hitherto been imposed by scarcity or absence of water, insecurity, exacting terms of land tenure, health conditions, or other causes.

Proposals are submitted for improving the water supplies of the towns of Mukalla, Rukeb and Shibam, and suggestions are made regarding the better utilization of the water of the Wadi Hazr at Meifa and the Wadi Hawash at Shihier.

Methods of increasing the ground water supplies at Gheil - Ba - Wazir are described, and numerous districts are mentioned where a big extension of cultivation would follow the sinking of more wells or the resuscitation of old works.

Various localities in the maritime plains are named where the prospects of tapping useful supplies of ground water at moderate depth are regarded as encouraging, and considerable space is devoted to the potentialities of the Wadi Hadhramaut and its major tributaries.

Finally, the water situation at Wadi Du'an, Abr Wells, and Balkof is dealt with, and views are expressed regarding the value of water conservation by tanks.

# THE WATER PROBLEMS OF THE EASTERN ADEN PROTECTORATE (HADHRAMAUT)

## INTRODUCTION

The contents of this report are based upon a month's journey through the Protectorate in company with the Resident, Mr. W. H. Ingrams, and Mr. Hartley, an Agricultural Officer lent by the Tanganyika Government. With the aid of motor-cars and the assistance of the Royal Air Force a very considerable part of the more interesting portion of the country was visited, and its water resources investigated in conjunction with agricultural prospects. The objects of the expedition were to investigate the feasibility and practicability of developing better water supplies for domestic, pastoral and agricultural purposes, and to consider ways and means best suited to increase the acreage of land under cultivation.

Using Mukalla as a base, the hydrology of the immediate district was first investigated, and a journey to Meifa undertaken. Proceeding along the maritime plains eastwards, the water situation was examined as far as Reidat - al - Abdud Wadud. From Shirh a route was taken inland over the high plateau to the Wadi Hadramaut, and that remarkable watercourse was followed from below Tarim to beyond Shibam before branching into the Wadi Ahmd as far as Hureighda. A flight in R.A.F. planes was then made to Wadi Du'an, and from there aeroplanes carried the party to Abr Wells and Balkof before proceeding to Mukalla and thence to Aden via Meifa.

The Eastern Aden Protectorate is composed of the following units:-

1. The Qu'aiti State of Shihr and Mukalla.
2. The Kathiri State of Seiyun.
3. The Mahri Sultanate of Qishn and Socotra.
4. The Wahidi Sultanate of Balkof.
5. The Wahidi Sultanate of Birali.
6. The Sheikhdom of Irqa.
7. The Sheikhdom of Howra.

Only some of these States were visited, but they included the most promising parts of the country for development. The total area of the Protectorate is roughly 60,000 square miles.

The absence of good topographical geological maps was a great hindrance and reliance had to be placed on the small-scale reconnaissance maps of Weissman and others for the location of routes and places except in restricted areas which had been surveyed. Fortunately the geology of this part of Arabia is not very complicated and the essential large-scale structural and lithological features were readily distinguishable even at a distance and often from the air at an altitude of from 3,000 to 6,000 ft.

The most important regions demanding water development are -

(a) The Wadi Hadhramaut between Tarim and Shibam and its major tributaries.

(b) The Meifa Valley.

(c) The coastal plains including Gheil Ba Wazir, Reidat and Shihr.

(d) The plateau country where occasional high-level depressions have led to an accumulation of fertile silt.

Each district visited receives independent attention in the body of the report. When travelling about the country, surprise was felt and expressed time after time at the lack of organized cultivation in areas where water was manifestly plentiful at a shallow depth and the soil had all the appearances of being fertile. On interrogating inhabitants, many explanations were given for the apparent lack of enterprise, but it became abundantly clear that sociological causes were to no small extent responsible for the neglect of much land.

Not only has the country long been cursed with tribal and personal vendettas and blood feuds but onerous terms of land tenure and usurious exactions by those with power have made farming unremunerative except in a few localities favoured by nearby markets, ample water and exceptionally rich soil. Constant strife and incessant warfare had driven pacifically inclined inhabitants to other countries and decimated, or rendered economically impotent, large numbers of peacefully disposed peasants. Through the instrumentality of the Resident, Mr. Ingrams, and the leading Sayids, a temporary truce had been proclaimed and faithfully respected in a number of districts with the immediate result that cultivation was being extended beyond the range of village protection. If the peace movement is to be consolidated and extended, it is essential that some occupation should be found for the people to replace the old system of warfare and toll extraction or plundering of caravans. In an extension of agricultural and pastoral pursuits lies the only chance of pacifying a rebellious nomadic population imbued with the spirit of independence, and this can best be accomplished by a wider development of water resources in parts where suitable soils exist for crop planting.

No useful rainfall figures are available, but it is known that the annual precipitation is low and its advent precarious and variable. There are no snow-capped mountains to sustain perennial flows in streams, and the rocks usually exposed are neither structurally nor lithologically favourable for the reception and retention of water. Generally the topography is such as to encourage quick run off of storm-water to water-courses with steep gradients that conduct to the sea before the land can be soaked and downward percolation initiated.

Effective barrages and obstructions have been constructed in some water-courses to delay the passage of storm-water or to deflect it on to land lining the river banks, and this system of conservation should be encouraged in every way, especially as the fresh silt deposited on the land has a fertilizing influence. Barren land may indeed be reclaimed by the casting of silt-laden waters in ground too stony or infertile to support any kind of food crop. Perennial streams are very rare and springs of useful magnitude infrequent in Southern Arabia, and the few that exist are utilized by the tribes wherever conditions admit, but reliance for perennial watering must generally depend upon ground-waters which receptive strata have absorbed in the rainy season and retained.

The accumulation of sub-surface water depends upon many factors such as the amount and incidence of rainfall, the character and disposition of the rocks exposed, and surface relief. When the strata are relatively impermeable, little disturbed from horizontality and deeply gouged by ravines which rapidly carry off storm-water, little can enter the ground unless its movement is artificially checked to give time for percolation. For this reason, ground-waters in useful quantities are generally confined to comparatively flat land where its movement above and below ground is resisted by frictional elements. Speaking generally, water in arid hot countries of low rainfall must be mainly sought in the

vicinity of water courses which convey the concentrated run-off of large areas at higher elevations and tend to feed by lateral and vertical percolation pervious strata over which the water spreads.

The Miocene beds so commonly exposed on the coastal plains are highly gypseous and they often contain extensive deposits of gypsum or anhydrite which is so highly soluble in water that vast caverns have sometimes been formed by solution along fissures and zones of disturbance. Enormous volumes of water enter such crevices in the rains and their surcharge is commonly marked by springs issuing at some point of weakness at an elevation which drains off their contents. Contrary to expectations, water derived from such sources is not so highly mineralized with sulphates and carbonates as the more stagnant supplies which impregnate gypsum-impregnated strata.

Without doubt a certain amount of water enters the Eocene limestones which cover such a great part of the country, but their compact and crystalline nature restricts percolation to fracture zones which cannot often be located or inferred from surface conditions: consequently, the search for water in such ground is exceedingly hazardous. Water which does enter such rocks may be entirely concealed by alluvial deposits. These hidden springs are the main feeders of the valley alluvial deposits which yield through the medium of wells the water for perennial cultivation.

The crystalline rocks of the country which form a shallow platform upon which the sedimentaries were deposited become sufficiently decomposed on their upper parts to admit water which also issues as springs after slow travel to some depressed point. Such springs are very plentiful and account for many of the surface and subsoil waters which escape down the main wadis of the country.

Viewed as a whole, it is surprising to find in so arid a country what a large volume of water does, in fact, find its way into the ground and travel by devious and intricate routes seawards. On its way to lower altitudes salts are dissolved from the rocks through or over which it traverses, and the degree of salinity depends entirely upon the nature of the strata met in its travel. Although no analyses of waters were made and testing was confined to taste, it can be said that few, if any, waters were found that were too saline to support profitable crops. It was indeed a pleasurable surprise to find so much groundwater in so rainless a country, and without doubt important areas could be developed by well-water if the farmers were given a square deal by the landowners and the marketing of suitable crops could be ensured without unjust exactions. Official help would almost certainly have to be given to cultivators who are far too poor to sink wells, purchase seeds, animals and implements, without the aid of money-lenders who would in time-honoured style keep them perpetually impoverished and in a state of veritable slavery.

Water is not so abundant that it can be wasted, and the output per well may be only about enough to support an acre or two of land, so that apart from such benefit as might accrue from the seasonal deflection of storm-water upon land near water-courses, reliance must be placed upon human or animal extraction of water. Large-scale commercial supplies of pumped water are only possible in a few places to which reference is made in the report unless a system of galleries is entertained whereby the equivalent of some score of wells could be directed to a single sump.

A very natural desire for a gravitational supply of water was expressed, and many requests for dams in water-courses were made by those owning land in the vicinity. If by dams is meant the impounding of water in river beds in the rainy season for later use, they can be condemned

without hesitation, as suitable sites are rare and in any case the water carries so much silt and debris in suspension that reservoirs would be filled in a very short time due to the torrential and brief character of the flows. Used as barrages to raise the river-bed high enough to deflect some of the storm-water into canals that would reach land otherwise left dry, they would effect a very useful purpose.

So great is the desire for gravitation supplies of water that extensive gallery systems have been made in a number of localities where subsoil water could be drained from beds lining the upper reaches of water-courses at an elevation that ensured a natural flow to cultivable land. Some of those seen must have entailed a heavy outlay and a fair knowledge of hydraulics; but due to neglect, faulty construction or imperfect alignment, fall of water table, or perhaps sociological causes, numbers were either no longer functioning or giving only a small yield. The system is sound and feasible if suitable provision is made for effective recharge of beds by maintenance of water-course level or other ways, and what is important the construction of such works could be performed exclusively by native labour.

The gallery system is still practised in Cyprus, 'Iraq and Iran where miles of galleries so often fringe the sides of water courses which during a flood charge the bordering alluvial deposits.

In parts of the country the only feasible method of obtaining water at reasonable cost is by impounding in suitably-prepared and properly located reservoirs where it can be stored over long periods. Rock tanks have been built by charitably-disposed citizens of means for the use of travellers along main roads, and in at least one case large deep rock cisterns had been built to supplement a town supply. On the high plateau earthen tanks designed to collect the run-off of rocky ground alone satisfy the requirements of travellers after the rains have ceased. Existing methods are capable of a useful elaboration by enlarging the size of the tanks, increasing their depth either by raising the height of bunds or by excavation, and puddling their bottoms and sides. Guiding walls and cut channels could be made to direct surface run-off towards the reservoirs. Heavy evaporation losses in open tanks can only be met by providing for the depth to bear some reasonable relationship to exposed water surface.

The opinion was commonly expressed that there is now less water than formerly and that wadis, springs and wells yield far less freely than formerly. Whilst unable to discover any evidence of changed climatical conditions, it may be that one of those periodical cycles of rainfall deficiency is being experienced and in several localities proof was found of past cultivation and irrigation on a large scale where today nothing but eroded mounds of silt, rotting stumps of palms or great spoil heaps mark the site of former canals and plantations. The appearance was reminiscent of some of the Mesopotamia plains between the Tigris and Euphrates rivers where there were once flourishing crops irrigated by an elaborate system of canals but now abandoned through neglect and wars.

The abandonment of areas so obviously intensively cultivated in the past is believed to be entirely due to sociological causes and not to any climatical changes.

From the context of the report it will be gathered that the prospects of extending cultivation are distinctly favourable in a number of the districts visited, and in many cases it would be unnecessary to do more than finance the construction of wells and instal willing workers on land subject to just conditions of tenure and a guarantee of peace. Without doubt the Wadi Hadhramaut with its big population and enormous resources offers the best opportunities for immediate development on a large scale,

but next in importance are the coastal lands in easy reach of ports through which surplus products could be safely moved or exported in case of need. Given peaceful conditions in the Protectorate it is probable that there would be a return of many people forced abroad by feuds and troubles, together with the much-needed funds to set in motion the normal trade channels. Agricultural prosperity would have its reflection upon the fishing industry of the coast which even today affords occupation for many people in connection with food production and manure manufacture.

Tobacco culture could be extended at a number of places in the coastal regions. Reference in particular is made to developments at Gheil Ba Wazir and Shihier where there is reason to believe that much water now lost could be made available at some little cost in pumping machinery and running costs. At Fawa, Hibs, Reidat - al - Abdud Wadud cultivation could surely be extended by sinking more wells or, if thought desirable, installing pumps in one or more shafts sunk to greater depths than those now in existence. Some of the places visited admit of no important improvements and others offer only speculative possibilities.

Meifa calls for some expert aid in re-arranging the canal system, but here large volumes of water are wasted that could be used for irrigating suitable land almost anywhere in the valley. Where canals could not be conveniently led to fertile areas pumps could be installed for lifting water the necessary height to irrigate cultivable land.

Reverting to the Wadi Hadramaut it will be noticed that there are almost unlimited possibilities in the broad expanses of fertile silt which clothe the valley floor for many miles, far more indeed than the present population could possibily utilize.

## MUKALLA WATER SUPPLY:

Some days were spent in exploring the terrain around Mukalla in hopes of finding some larger and more reliable supply of water for the town. The present supply is drawn from galleries driven into iron-stained sandstones flanking a limestone ridge to the north of the town at Bagrien. The effluent is led in an uncovered masonry channel to an open tank where it is aerated by cascading over a flight of steps, and then syphoned in a 6" pipe across the deep wadi and armlet of sea before running in an open masonry aqueduct to the city. The quantity could not be measured but at the end of January was of the order of 1,000 to 2,000 gals. per hour and quite insufficient for a city's growing needs, but doubtless the flow increases after rains. Several visits to the source led to the conclusion that little more could be done to augment the yield by any extensions of galleries in the vicinity of the present headworks, which are evidently the site of an ancient spring. The sandstones appear to be remnants of the Miocene beds which along the littoral belt unconformably overlie the Eocene limestone: and for some distance near the springs these beds can be followed round the hills and are found to yield small effluents of water used for gardens. Nowhere in the neighbourhood was any important development of sandstones found, and up the gulley alongside which the galleries are driven a deep vertical cut was traced in the sandstones until they came to an abrupt end. The steep limestone ridge above the springs was climbed and the contact between the limestones and the overlapping sandstones and shales could be easily discerned.

It was at first thought that the deep wadi which drains land to the north-west and is a continuation of an armlet of the sea would be likely to yield water in quantity as wells were found giving prolific supplies of water which, however, was found to have an unpleasant taste: but a more detailed exploration of the wadi led to an unfavourable opinion

regarding its value as a source of water supply. A certain amount of water is obtained from wells on the narrow flats between the sea and the high ridge which rises behind the town; but for geological reasons alone, sustained supplies of potable water could scarcely be expected. The steep hills behind the city are composed of igneous rocks which a capping of limestone which also encrusts the sides, and the strip of alluvium and scree upon which Mukalla is built is so narrow that any considerable withdrawals of water must eventually lead to access of sea-water. The ground, too, is badly polluted, as the town refuse is mostly deposited on the surface and sinks into any porous beds, so that well-waters must be very dangerous.

Investigations were next extended up the series of valleys running in a westerly direction between the coastal ridge and the high mountains to the north, and it was especially desired to visit the spring Qalia. The discharge from this spring had at great expense been conveyed to the outskirts of Mukalla in a masonry aqueduct by some benevolent citizen; but due to damage by floods and failure to repair, it functioned only for a short time. This highly creditable piece of work could even now easily be put in working order, although contouring the hill-sides and crossing wadis and gullies on standards it must always be exposed to considerable risk during rains on hills or floods in the valley.

The spring could not be reached owing to washouts on the road, but we walked sufficiently far to obtain a general view of the topography and geology of this region and to decide that these wadis offered much better prospects than any hitherto inspected. On the lower edges of the limestone ridges which border the valley, there still remain thick beds of sandstones many of which are coarse-grained, false-bedded and highly permeable consequently extremely suitable reservoirs for water, but how far they continue below the wadi bed it was impossible to ascertain.

In any case, they are likely to act as valuable feeders to any supply which wends its way seawards from the high peaks to the north and north-west and which must during rains occasion heavy flows of water into this valley system. The scarcity of soil and the broad expanses of gravel and boulders account for the absence of any agricultural operations in this direction.

We regard a site near the village of Manousirah close to the junction of the two main wadis as the most promising for Mukalla's water supply and feel satisfied that very large quantities of potable water could be found at a depth somewhat above sea-level, say 20 ft. Having no maps, great difficulty is found in fixing spots and distances or names of places so that any figures given must be regarded as approximate.

The location of waterworks at this spot would necessitate pumping, and on the basis of 60,000 gals. a day raised 100 ft. in 12 hours working a single 7 h.p. diesel oil-engine driven three throw ram pump would cost about £200. c.i.f. and the running costs would be about Rs. 4 per day with fuel at 8 an. per gallon. A duplicate set such as we always advise for town waterworks would double the capital figure. We hesitate to recommend what would appear to be the most obvious course of a long pipeline to the city tanks as all local waters are highly charged with salts of lime and iron which not only cause bad corrosion but lead to incrustations which quickly choke the pipe. Experience in Berbera, British Somaliland, has shown that a solution for this trouble is not easy to find, for it is uncertain whether aeration, sedimentation and perhaps filtration will remedy the difficulty. It may be that a non-metallic pipe would alleviate, if not cure, this trouble, as no deposit was observed in the aqueduct although steel pipes leading thereto were so thickly furred with a hard incrustation that in some cases only a $\frac{1}{2}$" hole was left in a 6" pipe used for the syphon across the wadi. Until experiments have been made with short lengths, we are inclined to advise pumping water into the existing aqueduct which should, however, be covered and reinforced at weak spots. A 6" pipe-line would be necessary to lead the water into the existing aqueduct. From the small-scale maps in our possession we are unable to measure the distance. A price of 4/- per foot might be taken.

We appreciate fully the objections to a pumped supply but fear there is little chance of developing a gravity supply unless one went so far afield that the risk of damage to aqueducts or piping would be serious. Water might be found sufficiently high up the western valley to give a gravity fall to the city, but until we know more we would hesitate to advise the purchase of piping, and a long aqueduct is too risky.

## HARSHIYAT

An impressive oasis of healthy date-palms with undergrowth of lucerne and vegetables is here watered by a perennial spring issuing from gypseous sands and marls that form a fringe round a veneer of limestone capping an igneous range. The water is warm and escapes from holes at the end of a small gulley from which a trench has been excavated to the cultivation, and it doubtless owes its origin to infiltration of rainwater into the limestone and sandstones flanking the igneous ridge. The volume is of the order of 5,000 gals. per hour, and the salinity is not unduly high judged by the taste. Other springs of lesser importance trickle into trenches which at Maaz are excavated in granite pierced by dark basic dykes. At Tilla Es Soufla a small oasis of palms is supported by the effluent of springs, and we saw Arabs engaged in opening up an old spring by deepening the channel to induce a flow from a spot where the water level had fallen below the original bottom of the canal.

We fear little can be done to improve matters as the oases are high up in the "Joul" with no useful catchment or extensive water-bearing beds around. The people seem to be using every likely source, and any attempt to enlarge present works would inevitably reflect injuriously on present supplies by lowering the water table, thereby throwing the present canals into disuse. Within the area of cultivation a series of wells might enable some of the water to be recovered which is not consumed by the palms and percolates downwards.

## COASTAL PLAINS - EAST OF MUKALLA

Flying along the coast from Mukalla over Shihr to Reidet - al - Abdul Wadud a splendid view of the wadis and the lessor drainage systems was obtained, and when crossing the Hawash the exact spot where water first appears on the surface was clearly visible. All the major wadis have their birth in the foothills and many must drain off considerable volumes of water seawards. Near the coast water was frequently held up by sand bars, and pools of brilliantly tinted water marked these spots where algae flourished transmitting vivid red, green, yellow, blue colours to the stagnant water. Another feature that escaped notice when motoring along the coast was the present of great lava sheets which starting from some points in the foothills either spread outwards as enormous fans or followed wadis which had an earlier existence. Many of these were obviously of post Miocene age and it may be of even more recent age. These black basaltic sheets with pitch-like wrinkles on their surface were first noticed north of Hawash and they appeared at intervals to Reidet and beyond.

Owing to the horizontality of the Miocene and Pliocene deposits near the coast, broad flat strips of country furnish very favourable sites for agriculture where the soil is suitable and water is available. Farming along the coast is now restricted to narrow strips of silt in or alongside the wadi beds to which flood waters can be deflected during spates, but there is a pronounced absence of wells for supporting perennial irrigation. The first impulse was to suspect the existence of

water, yet when seen in section the strata did not appear unfavourable although often highly gypseous and argillaceous. Occasional wells seen or referred to by the Arabs proved that water of potable quality was in fact being taken from these strata, and wadi beds followed up stream often showed water or exposed strips of damp puffy earth betraying the presence of water within reach of the action of capillarity. Gypsum is certainly everywhere in evidence, but this has not prevented the promotion of a big tobacco-growing industry at Gheil and elsewhere. The amount of salts in solution in gypsum water seems to depend upon the freedom of circulation: the highest concentration of salts possibly following prolonged stagnation. Wadi beds were traversed skirted by banks in which thick beds of interbedded crystallized gypsum outcropped, and large slabs of selenite littered the surface, yet numerous shrubs flourished and date-palms appeared to be little affected by the sulphate waters.

Nowhere was any considerable thickness of Miocene beds exposed for examination, but as the series contains beds capable of absorbing and yielding water, the prospects of penetrating aquifers is reasonably favourable, and the static water-level is not likely to be so deep as to discourage irrigation if the quantity is moderate and the quality passable. On parts of the littoral a sufficiently hard crust or pan has been formed to impede the process of tilling in the early stages, but it should be possible to avoid such areas and confine well-sinking to regions where a workable deposit of silt covers the surface. Wells should be sunk as near water-courses as possible, as the quality may be better due to the more frequent flushes as well as freer subsoil movements. In those broader wadis with stretches of fertile silt it would be necessary to construct wells with a masonry surround carried high enough to escape floods which otherwise carry silt and gravel into the well.

The trouble taken to develop gravity flows of water was well illustrated at a small oasis near Ruijan where deep trenches had been dug to conduct a small flow of water which supported not only a clump of date-palms but also a plantation of henna, tobacco, melons, onions and other odd vegetables besides elb and tamarind trees. Where the flow of water is so small it is collected in a cistern before being run onto the ground. A considerable volume of water appears to run to waste in the Hawash, and a scheme for pumping some of this water to the flat plains to the west of the valley seems worth entertaining. The total height to which the water would have to be lifted would only be of the order of 50 ft. so that it falls well within the range of economic use if the land proves suitable and the people are available and willing to pay a reasonable rental for the water. On the basis of a 10,000 galls. per hour plant, say the equivalent of twenty wells, the cost of machinery would be about £100 and the cost of water Rs.$^{2}$. per 3" watering per acre. Windmills might prove useful here but we have no particulars of the intensity and prevalence of winds in this district. Obviously the growth of crops requiring a minimum of water should be selected where its recovery by pumping is necessary. The soil in the coastal area is generally fairly heavy and not likely to cause excessive losses by downward percolation like the more sandy soils of some districts.

## RUKEB

Mr. Ingrams expressed a desire to give the 4,000 inhabitants of this coastal village a better supply of water as they now rely for their drinking water upon the donkey carriage of some 600 skins (3,000 gals) a day from Buweish. In the village abundant supplies of water are available at 29 ft. in gravel beds, but it is so saline that it is undrinkable, although used for washing purposes. The village is located at one of the mouths of the Wadi Harshiyat and is separated from the sea by a line of sand-dunes; but although the immediate district was examined, no very encouraging spots were found as the scour channels are ill-defined and give no evidence of vigorous flows.

The nearest important wadi is the Lusul which enters an arm of the sea at Buweish, and here a very prolific well, Bir Alian, not only waters a garden choked with produce but furnishes all the potable requirements of Rukeb without signs of depletion. Other wells in the district are alleged to be less prolific and to give a more mineralised water, and it may be that this particular well only a short distance from an inlet of sea-water has tapped the main drainage channel of the valley.

We are not prepared to affirm that a methodical exploration of the Rukeb district by shafts or boring would not disclose the existence of potable water in needful quantities, but this might prove a slow and expensive undertaking and we are inclined to advise that use be made of the Buweish water either by arrangement with the owner of the present well or by sinking another in the vicinity. The distance between the two places is only a mile or two and by trenching or tunnelling the ridge which separates them water could be run with a minimum of lift through a channel or a pipeline. The necessary head could be given to the water by lifting from the well to a height which would give a gravity flow to Rusib, say some 20 to 30 ft. including the suction lift of 12 ft. in the well. A 12 ft. windmill, costing with pump and piping £130. would comfortably perform the task of lifting up to 1,000 gals. per hour to the desired height; but if animal power were preferred, water could be drawn in the usual way to the height of a platform on which a tank was placed to receive the contents of the skins. A short pipe-line might be used to convey the water over the small distance before the ridge is reached.

## HIBS

At Hibs a Government garden was entered, so packed with tropical plants that their further growth and development were impeded; but it gave some idea of the fertility of the ground when amply watered and given some little attention. Irrigated by a perennial flow of water, we found growing in profusion dates and coconuts, pomegranates, figs, bananas, papayas with an undergrowth of grapes, sugar-cane, lucerne, maize, etc. Near the garden was a well about 50 ft. deep worked by bullocks and said to yield large quantities of water without exhaustion. Leaving Hibs we soon ran into a belt of Pliocene gravels capping a sandy-clay series forming conspicuous ridges parallel with the coast. Without doubt more land could be cultivated if wells were sunk to tap the subsoil water proved to exist here.

## REIDAT - ASH - SHIGAR (RIYAN)

This place was twice visited, once when making the coastal journey to Shihr and later with R.A.F. planes to consider a water-supply scheme for a proposed aerodrome. The landing-ground lies on a part of the broad littoral belt which follows the coast for miles where not cut up by water-courses which carry inland run-off to the sea. The gravel surface is a mere crust of re-cemented debris lying upon a horizontally-bedded and little-disturbed succession of gypseous marls and sands in which thick beds of gypsum and slabs of selenite occur. Both north and east of the ground sections of these beds are exposed in low cliffs bordering scour channels, the floors of which are often composed of gypsum with a mosaic of parting lines. This series is likely to yield water at no very great depth but it is almost certain to be highly mineralized and objectionable for domestic purposes: consequently, one hesitates to advise the sinking of wells on or near the landing-ground. The wadi to the east offers better prospects as there may be deep channels filled with alluvial deposits which receive a less mineralized water from the distant hills. Some support for this view is found in the presence of fresh water in this wadi near the sea after it has followed a circuitous course before breaching a broad belt of sand dunes.

A favourable site for a trial well would be in the dry water-hole beside the clump of tamarisks near the north edge of the dunes not far from an abandoned well. We regard the supply in the sands near the sea as too precarious for reliance, and should potable water not be found where indicated, we would prefer to have the requirements piped from the Wadi Hawash where there is a permanent flow of water which should meet the rather exacting requirements of the R.A.F. This scheme would involve the laying of a 3" pipe-line and the installation of a pump and engine below the west bank of the river at Shihier. The cost of an installation to deal with 1,000 gals. per hour would be about £70. c.i.f. plus cost of 5-mile $2\frac{1}{2}$" pipe line, say £350.

## SHIHIER

The pleasant garden of a Mukalla official was used as a midday halting place whilst on the way to Gheil, and its position alongside the Wadi Huwash ensured an abundance of water for cultivation of palms and garden produce. The Wadi Huwash was running quite a fair stream of water over a sandy bed, with every appearance of being suitable for tube-well development. The flow is said to be perennial and, if so, the river would appear to justify some further investigation either by a barrage up-stream to lift the flow sufficiently high to reach land now unused or to pump water from wells in the stream bed for use on adjoining lands. Naturally existing water rights would have to be studied before entertaining any important scheme, for they are so jealously guarded by those with real or imaginary rights that their adjustment might occasion no little difficulty. Something should however be done to use water which now runs to the sea unused.

The water is likely to be fairly heavily mineralized as the strata all around are highly gypseous, but that this is not a serious detriment to cultivation is shown by the garden where dates, coconuts, papaws, pomegranates, egg plant, tobacco, tomatoes, onions, etc., were being grown and looked healthy.

Elsewhere a proposal is made of using some of this water for the aerodrome at Riyan.

## SHIHR

This Port of 6,000 inhabitants derives its drinking supplies from Tobala where a number of hot sulphur water springs issue from crevices near the summit of a hill some seven miles from the town. The water is unpleasantly hot to the hand and is charged with sulphuretted hydrogen ($S.H_2$) which escapes freely near the vents, polluting the air with a pungent odour of rotten eggs. The effluent of each spring is led in a gulley to ponds and cultivation or to a cistern which supplies the town with about 1,000 G.H. An aqueduct made of lime or cemented masonry leads the water to Shihr contouring hills and crossing wadis by support on columns or by syphoning in pipes. It has been unequally graded and at places is broken and piping introduced or a receptacle has been built to feed water into a pipe (syphon) crossing uneven ground or dunes. Over most of the distance the aqueduct is open and people and animals draw from it for drinking, washing, and otherwise interfere with the supply. An open concrete cistern in the town receives the flow and collects the night supply, and around the base is a number of brass taps from which the inhabitants draw their water.

There are numerous wells in and around the town, but the Tobala water is said to be more palatable than that from wells as the obnoxious $SH_2$ is quickly lost in transit. The installation has cost, it is said,

about £1,500 and probably serves its purpose, for we were told that pipes are quickly encrusted and corroded and would need frequent replacement. If chlorinated at the town tank the supply should be quite wholesome, although it would be preferable to have the aqueduct covered throughout its entire length to avoid contamination en route, taps being provided at intervals for people to draw off water for themselves and their animals. Wells in the town have water at 25 ft. to 35 ft. depth and from the wadi to the east water could be pumped if it was needed.

As Shirh is an important seaport and could export produce grown locally, special attention was given to the cultivatable land within easy reach of the town, near the village of Yiradef. We were conducted to a broad flat plain of fertile silt which was at one time intensively cultivated with water from wells and by water carried from a distance in galleries now mostly abandoned. Around the village were once sixty working wells, our informant said, but raids and exactions by Bedouins had led to the virtual abandonment of this rich district. The few gardens and date-palms being watered by hand-withdrawal of water were in a wretched state of neglect, although some of the installations, no longer worked, had been most carefully and skilfully executed. Further towards the hills were found broad stretches of flat silt showing unmistakeable signs of former cultivation in places, and across the country for some miles ran several deep galleries, marked by strings of wells, which once conveyed water from a system of infiltration chambers with intakes near the hills to the north.

The absence of wells and cultivation on land so obviously suitable for crops led to some speculation as to the existence of water under what seemed favourable conditions, but whilst debating the prospects of ground water we came upon a well with water at 30 ft. alongside land which was cut into sections for irrigation, thus disposing of the question as to whether there was water or not. Other wells near the village had water at 20 ft. and were being used. A descent to one of the galleries was made and a small flow of water was found.

On following the wadi towards the sea, other neglected lands suitable for cultivation were crossed and we found relics of an old masonry dam which once deflected flood water on to the wadi sides. Here also water is available at a depth of about 13 to 20 ft. and a number of small plots are being worked by cultivators using well water. In the wadi bed itself was found a well from which water of high quality was being drawn from a fine unconsolidated loose sand below a bed of gravels at a depth of only 6 ft.

As it seems apparent that produce can be profitably grown in the district by well-irrigation, it would seem preferable to make initial experiments with well-water before entertaining any reconditioning or extension of galleries. The people are too poor, they claim, to sink wells or purchase animals; but if security of tenure at reasonable rentals could be arranged and all exactions and forms of blackmail stopped, it should be possible to bring into cultivation a considerable area of land now unworked. Much of the land is owned by capitalists, and suitable terms with them should be negotiated before any financial assistance is given to cultivators who develop land now unused and yielding no revenue to the possessors.

## REIDAT - AL - ABDUD WADUD

A flight in R.A.F. machines to this place from Mukalla on 27th January afforded an opportunity of seeing the maritime plains beyond Shihr. The most striking change noticed was the prevalence of basaltic lava sheets which, having their origin in the foothills below the high plateau, spread fanwise towards the sea, often filling wadi beds for some distance before opening out. From the air they could often be traced beyond the shore-line where they formed reefs upon which the waves broke. The town itself lies

upon the bank of a wadi which drains ground to the northwest, but due to the topography and sand encroachment there is little land available for cultivation in the vicinity: that suitable for agricultural pursuit is already occupied and planted with wheat, as it is irrigated by wells giving an abundance of water at a depth of about 18 ft. from permeable gravels. Between the landing-ground and the town the surface was strewn with drift sand over which walking was very tiring.

Proceeding several miles up-stream, a broad basin was reached dotted with fields of healthy wheat and other plants dependent entirely upon irrigation by widely-scattered wells. Here there appeared to be considerable scope for extension, as the soil was described as uniformly good over the basin and water was said to be plentiful at a depth of about 35 ft. The soil is likely to be rather more fertile than the average, due to admixture of the calcareous earth with basaltic debris which generally produces a dark rich soil. Tobacco was being extensively grown, indicating the suitability of the region for that crop.

On interrogating the people, the usual excuse of poverty was given for failure to sink more wells and extend the plantations. If this is the main cause, and not onerous conditions of land tenure and other exactions, some financial assistance by advance of capital would seem the most obvious course to pursue. As in all cases there is a limit to the amount of water that can be abstracted without an undue depression of level and depletion of supplies in any particular area, but this basin is so well located for replenishment that no immediate fears in this respect seem warranted. Wells can be inexpensively and quickly sunk here, and no difficulty should be found in extending the cultivation if financial assistance was given for sinking wells and planting up acreage, provided reasonable rentals are fixed for farmers. The area seems a pleasant one in which to work.

## FUWA

A visit was paid to Fuwa, where land under Palace or State ownership was worked under various conditions. At Fuwa the Wadi Kherba reaches the sea, and at all seasons flowing water is used for irrigating palm-groves and cultivation some few miles up-stream. Various wells were visited in which water was standing at 15 to 18 ft. from the surface, and these were used for watering healthy, if scattered, patches of grain, vegetables and date-palms. Healthy crops of tobacco, lucerne, millet and maize were seen as well as plantations of sweet potatoes, tomatoes, cassava, egg plant, ochroes, proving thereby the fertile character of the soil.

On one farm of five acres, for which the rental to the Government was Rs. 15 a year, eight men and four bullocks were engaged and the crops were said to yield a revenue of Rs. $2\frac{1}{2}$ to Rs. 3 a day.

The strata exposed near the coast were cemented beach formations, a mixture of sand, corals and pebbles and wells sunk into the formation were said to yield water freely.

We were unable to obtain any reliable information about yields of wells and their behaviour with the seasons, but the situation of Fuwa is extremely favourable for the development of considerable volumes of water, at least within a reasonable distance of the Wadi. Cultivation appeared to lack co-ordination and seemed to be in need of skilled direction or guidance, and it is much to be regretted that this nearest cultivable region of any extent to Mukalla should receive so little consideration. Properly organized, the land at Fuwa should be made to yield first-class crops of vegetables, fruit and produce for the Mukalla market. Suitably-placed wells might conceivably prove sufficiently prolific to justify the installation of power pumping units designed to irrigate much larger strips of land than

the existing wells. The conditions do not justify expectations of striking deep-seated water by drilling.

## MEIFA

Some twenty miles west of Mukalla at Ras - El Kalb is situated the delta and outflow of the Wadi Hajr which drains a large sector of hilly country to the northwest and has deposited a fan-shaped stretch of alluvium seawards after its emergence from the foothills. A spot east of the delta was reached after an exciting voyage in the Sultan's home-made motor-propelled dhow Saleh, and a landing was effected in fishing canoes on a sheltered beach with our belongings. The river has a perennial flow which at the time of the visit was probably of the order of 10 cusecs, although much water had been taken off and used up-stream. Within the neighbourhood of the village of El Sifal, which was used as a base, three canals served to irrigate a fair but undetermined acreage of land where lucerne, dates, dura, and a variety of vegetables were grown.

Excursions were undertaken about the cultivation and along its borders in order to observe the Arab methods of irrigating and planting and also to ascertain the general nature of the soil, the drainage conditions, and the character of the ground outside present development. A circular flight over the area below El Haila was later made during the journey to Aden, when a splendid view of the whole region was obtained at a low level and the patchy nature of the cultivated area was particularly noticeable. The marked contraction of the valley inland was also very noticeable.

Certain low-lying parts were found to be badly waterlogged, exposing in places sheets of surface water skirted by broad strips of salty, puffy earth. Tamarisks thrived in these areas, but land with water within the range of capilarity is quite unsuitable for growing most classes of crops. Sand-dunes and drift-sand had encroached over other expanses of alluvium, but nevertheless when watered the land supported crops, although great volumes of water must be absorbed. Land covered with a fertile silt sufficiently high above the water table or the level of the canals to ensure effective drainage was supporting crops that had a very healthy appearance quite comparable with those of Lahej and Abyian.

Scattered about the delta is a number of hills composed entirely of limestones, and several of these were climbed in order to observe the distribution of drift-sand, cultivation, and the course of the river which winds its way about the valley where not confined by rocky gorge or high banks. The river water is clear and runs swiftly over a sandy, gravel bed with no large boulders. Canals take off at intervals where temporary obstructions of brushwood and pebbles had been placed in the river to deflect some of the water from its course. The fairly steep gradient of the bed, perhaps 1 in 180, made this possible, and the procedure was assisted by the winding course of the river. In flood the river must bring down considerable quantities of silt which could be used for rejuvenating and improving land now outside the region of cultivation.

A journey made along the eastern fringe of the river cultivation led across broad alluvial flats with a surface covering of rubble and pebbles having a most unpromising appearance, but it may be quite deceptive owing to the strong winds removing top silt and leaving a concentration of rock fragments on the surface. At the village of El Haila we found signs of past cultivation on such ground almost to the base of the limestone ridge at the foot of which the village is built. Erosion channels caused by rushes of storm-water from the hills to the east break up areas, but canals could be led along this high ground where certain types of trees and plants would grow whilst new silt was being collected.

Some distance beyond the village of El Haila a sheet of basalt was crossed lying immediately over limestones, but otherwise the rocks in the district are all crystalline limestones on the west and basic igneous rocks on the east. From the air other patches of basaltic lava were observed on the other west bank of the Wadi Hajr, and at least one crater came in sight. The silt appears highly calcareous but is well mixed with siliceous and other crystalline fragments which lighten its consistency.

The conditions at Meifa are in some respects more favourable than at Lahej, for the river in its lower reaches does not flow in a deep channel with steep sloping sides, but winds about a fairly flat area from which canals can be led off without long, deep cuttings to reach flat areas downstream. Only in parts are the canals at such a depth as to ensure both watering and drainage of the land, a very important matter where there is a superabundance of water. Some of the cultivated ground seen was certainly water-logged and sour. With a more skilful alignment of canals or the drainage of low spots by trenches, much land now overgrown with tamarisk or impregnated with salt efflorescences could be reclaimed. This especially applies to the old bed of the river which once flowed eastwards of its present course, where rushes, sages and tamarisk now overgrow salty swamps or dunes. We found the Arabs laboriously levelling off sand-dunes after felling and burning the tamarisk in order to provide potash fertilization for the soil, and it was difficult to understand this conduct unless it is dictated by some circumstances other than agricultural, such as sociological where so much flat and fertile land was available.

With such favourable conditions for cultivation of crops one naturally sought reasons for the neglect of so important a district, for with an abundance of perennial water available water rights would hardly seem to come into the picture. Heald, in his Report, estimated that some 10,000 acres of land might be put under cultivation in the lower 65 miles of the river, and his map indicates fairly clearly what ground could be brought into immediate use. By the methodical planting of trees such as date-palms, coconuts, tamarisk, elb, or casuarina, mangoes, figs, etc., windscreens could be formed which would probably control the travel of drift-sand in areas where crops could be grown. The banks of canals could be planted with trees or oriented in such a manner as to permit of greater depth so that they would form both supply and drainage systems to the land. When watering, the deeper canals are temporarily blocked by sluices to raise the water to the height of the land. Mr. Hartley saw nothing to suggest that plant diseases were an adverse factor in the situation. The bad health of the indigenous population is notorious, as a malignant form of malaria is rampant, but it was clear that some attention to the housing of the people and the siting of villages would cause a marked improvement.

This wonderful delta of the Wadi Hajr certainly deserves the most serious attention for, given equitable terms of land tenure, security to the population, assurance of markets without undue levies, and some skilled advice in the watering and drainage of the land, the region should become one of the most prosperous in the Hadhramaut. One further essential to success seems to be attention to the health situation which could be immeasurably improved by adopting recognized precautions against malaria and transferring villages to suitable sites. Those working in the delta were low-caste Sibyans, who seemed terribly impoverished and were living in the most primitive style. So thick were the mosquitoes that without nets and flit our brief stay at Meifa would have been rendered almost unendurable and would certainly have been followed by fever. Little and Heald in their reports refer to the unsatisfactory health situation and to their own discomforts and sickness when there.

## GHEIL BA WAZIR

Arriving here in late afternoon after a motor run from Mukalla, it was a revelation to find after so many miles of barren wastes a region growing healthy crops of tobacco and grain irrigated by streams of running water. Around the ex-Sultan's palace, where accommodation was provided, was a walled garden stocked with produce, palms and trees, and a swimming-pool in front of the house. Here is stationed the Indian expert on tobacco cultivation engaged on investigations designed to improve

the quality and enlarge the scope of tobacco culture and usage, and he accompanied us on a visit to the cultivation and to the "springs" which supply perennial supplies of water. The site of the springs turned out to be large solution caverns in gypsum where the collapse and subsequent solution of the roofs has led to the formation of irregularly shaped basins filled with deep blue water. From these pools are led subterranean galleries which conduct the outflow on a suitable gradient to the plantations, the route of these galleries being marked by a line of shafts through which the excavated material was removed and by means of which they can be cleaned out. Two such pools were seen, one of which was located at the foot of a hill where solid gypsum was exposed at the surface. Evidence of the extent and size of the solution channels is provided by the large and continuous flow that emerges from the galleries, being of the order of some million gallons a day, say 2 cusecs from a single gallery judged by appearance.

Near the gypsum pools at Alguf are the tobacco nurseries where the seedlings are reared with well-water drawn from many wells 48 ft. deep which are separately owned and worked for the culture of young plants. The reason given for the distant nursery was that the water was more suitable, but it is difficult to believe that the output of the wells should differ to any marked extent from that flowing from the pools which drained the same source. A more probable explanation is that it is a preserved industry controlled by people who have always followed this occupation. The low cost of Rs. 1 for 400 plants certainly gave no cause for charging the growers with cupidity, and the continued support of these expert nurserymen should rather be encouraged than discouraged.

Without doubt the supply is dependent upon rainfall, and the volumes available vary both with season and with the annual precipitation in the neighbouring catchment. It is usual to find that waters derived from solution channels in gypsum vary in quality from place to place, and analyses may prove this to be the case here. The inhabitants declare that the supply has diminished in recent years and that fairly large areas have been thrown out of cultivation by the failure of a gallery system which led water from the head of a wadi to near the town. Mr. Paul, the tobacco expert, had just excavated a well in the midst of land which was formerly planted, and water had been encountered at a depth of 60 ft., but the supply was not large and the cost of abstraction was said to be uneconomic under the existing conditions. The excavation was a needlessly big undertaking, some 20 ft. square in compact gypseous sandy clays, the walls of which held up firmly, and its cost had been £600. We should have advised the construction of a much smaller diameter well carried to a greater depth if the sides held up without support, and having lateral headings if the nature of the strata admitted, as seems likely. In this way a larger percolation area is provided and much more extensive storage capacity is formed below the static water-level. Now only 6 ft. of water or some 16,000 gals. collects.

The Governor of Gheil was anxious that some kind of dam should be built across the wadi which carries flood waters to lands in the vicinity. Although possibly feasible it is hardly a course we recommend, for the reason that percolation and evaporation losses would be high and the reservoir formed would very soon be filled with detritus and silt following heavy spates, gradually reducing its capacity to nil, for there is obviously insufficient water to provide for sluices that would enable early flushes to pass away before closing the gates. As a means of improving the yield of wells or galleries in the neighbourhood such a dam would undoubtedly prove beneficial; but its cost, expense of upkeep, and practical utility might not find compensation in results. We regard as much more useful the system of galleries already made but which have been allowed to fall into disrepair and disuse. A line of such galleries was followed to its source alongside the wadi and sufficiently up-stream to give a gravity flow to the gardens round Gheil. Having been out of use for many years and almost entirely neglected, both headworks and galleries had suffered so much damage that their resuscitation might prove more expensive than new works. In any case we found no water either in the

wadi bed or in the shafts, which were mostly infilled with debris or had collapsed. The initial cause of the disaster was said to be an unusally big spate which demolished headworks and galleries where located along the wadi sides.

It may be that since the advent of this meritorious and admirable piece of work the local water table has fallen, due to lower rainfall; but in any case it would be unwise to consider any repairs until proper tests had been made for water by sinking shafts to the depth of the gallery floor near the headworks. Perhaps the large masonry-lined chamber in the river-bed now filled with debris could be cleaned out at less cost than sinking a new shaft. If water was found, pumping tests would quickly demonstrate the strength of the water source and enable a decision to be reached regarding the wisdom of re-opening the galleries or making a new system.

One very obvious and simple course is open to the Authorities if they desire more water and do not mind the little extra cost involved, viz., to employ a pump for lifting water from the gypsum caves into the galleries when the volume decreases as is probable towards the end of the dry season. It is practically certain that the galleries do not drain the gypsum caverns at the level to which they are driven, and it is most probable that greatly increased quantities could be obtained by pumping. The power needed to raise 2 cusecs, say 45,000 gals., per hour 10 ft. would only be about 6 h.p. entailing a fuel expenditure of 8 gals. of diesel oil a day, say 4/-. The cost of an oil-engine driven centrifugal unit would be about £125. One such outfit could be used at each gypsum pit and it would appear worthwhile to make some tests at one before deciding on a final size. Should the depression of water not reach 10 ft., the power consumption would be proportionately lower.

## SHIHR - TARIM ROAD

The road from Shihr to the Wadi Hadhramaut at Tarim enters the mountains some miles to the west of Shihr and, after crossing a succession of low dipping strata of Pliocene, Miocene and possibly Oligocene age through a wadi bed, enters limestone country from which it never emerges. On the edge of the maritime plains all exposed beds, even those of Pliocene age, assume some dip, and changes in dip generally indicate lines of fault. Within the foothill country the scarcity of soil and water is responsible for an almost entire absence of cultivation or villages, and until Ma'adi was reached nothing but an occasional thorn bush and a few other hardy shrubs broke the monotony of rubble-strewn barren wastes with gentle inclinations corresponding with the dip slopes of some more resisting bed. Deep down in a narrow gorge at Ma'adi is a mere string of date, arica and betel nut palms planted on small stone terraces built along the wadi floor and sides.

From Ma'adi the ascent is by steps to the plateau tablelands until about 6,000 ft. is reached. The topography is typically table-land with flat stretches of stony ground corresponding with some resistant bed lying almost horizontal. The stony appearance of the surface is somewhat misleading, for the loose fragments are embedded in fine silt into which the car often sunk and flung up clouds of impalpable dust, and deep ruts showed how soft was the ground after rain. High winds were responsible for the bare sharp-edged rubble which littered the surface: all angular and irregular but often burnished detached fragments. At times stretches of hard rock denuded of all loose material were followed, and in other places the surface of limestones along the track had been polished like marble by the padded feet of camels after centuries of travel. Drainage channels were very infrequent, the flat surface being as a rule suddenly gashed as by a half round gouge forming canyons with steep sides and often vertical walls. An intricate network of deep canyons draining first north and then south has forced the road to follow a very irregular course and lengthened the land route very considerably. As each successive platform

was reached, new flat-topped hills appeared dotted over the country, the upper hard band responsible for the pyramidal shape being underlain by a yellowish, shaley clay often glistening with selenite and calcite crystals. The more rapid denudation of the soft shales below a hard bed accounts for the peculiar landscape of steppes. Only on a few rare occasions were inflected beds noted and the most striking fold near Reidat - al- Miara had such gentle dips that they could only have been measured by levelling. A repetition of the sequence appears to be due to a succession of step faults with downthrow on the coastal side up to the divide. Although scores of sections were examined, not a single fossil was found, but the exposed rocks were almost certainly the Eocene calcareous series which conformably overlies the Cretaceous sandstone group nowhere seen on the road until a descent was made into the Wadi Hadhramaut near Tarim. Flints, usually darkly-stained red with iron, were conspicuously distributed about the limestones, and occasionally long acicular or bunched clusters of calcite crystals were noticed. The joint planes and exposed fragments of limestone were often blackened with a coating of oxide of iron.

Many of the gullies were gouged out in stages, the upper broadest with amphitheatre-like, abrupt end being followed by a lower stretch of level plain in which was denuded a second gully with the same characteristics but narrower, the last of two or several being nothing more than a narrow, steep gorge with vertical sides. Although strips of vegetation and thorn trees were observed in the deep major wadis where they attained a fair width in consequence of the union of many scores of minor canyons, no running water was ever seen or reported, and the Bedouins have to depend either upon wells in the deepest wadis or in tanks or mud pools designed to collect and store rainwater falling on a rocky patch of ground where the run-off would constitute a high proportion of any precipitation.

At Reidat - al - Ma'ara some villages have been founded on the banks of a high level depression with good silt accumulations where a few, if small, yielding wells barely serve to support a settled population. One well in use was found to be 111 ft. deep and yet the supply was described as very small. Another well Quazu was dry at 120 ft. A few other wells in the Wadi bed gave somewhat precarious yields at depth varying from 16 to 42 ft. After rains the shallow wadi wells would likely give fair yields of water, but the deep limestone wells on the edge of the wadi would not be likely to derive much benefit from anything less than prolonged rains. At least one deeper well is needed, but without skilled advice it is doubtful whether the local diggers could negotiate the very hard rocks that would have to be passed. Ventilation of a deep well is also a source of some difficulty without suitable plant. Where not drained off by deep nearby gorges, there are reasonable prospects of striking water in the limestone series for they are well-bedded with much vertical jointing and solution channels which would facilitate entry of water at convenient spots. The intervening shale beds are likely to impede vertical descent of water, but they are doubtless sufficiently fractured in places to admit of some water at times: indeed, exposed clay bands often exhibited indications of water absorption by growths of vegetation which sometimes gave their outcrops a green sheen. Useful supplies of water might be struck at depths between 50 and 200 ft. in many of the broader wadis where villages have been established, but the hard nature of the limestones imposes almost insuperable difficulties in well-sinking with the primitive tools used by the Arabs.

The best means of developing water would be by boring, but the high cost of transporting a rig to such inaccessible parts and the fuel and staff difficulties rather tend to discourage the use of power-propelled mechanical drills.

It was indeed surprising to find so many villages and so much cultivation in the wadi at Reidat where water is so scarce, but a lot of flood crops are grown in the rains and no doubt much water percolates into the ground at that period. At the villages of Ard'ha, Lugna Dhonuba and Quzu, wells were inspected with water at depths of 24 to 120 ft. and improved results might reasonably be expected by carrying these or new shafts to greater depths with the aid of more suitable tools.

## RISIB

Risib assumes importance now that a landing-place for planes has been prepared on the Joul above the wide fertile wadi which drains a somewhat restricted area of tableland. Here the inhabitants of the many villages are forced to rely upon impounded water in the dry season, and a number of quite useful tanks have been built on the edge of side gullies carrying water after rains. They have capacities of between 1,000,000 and 1,500,000 gals. and are provided with masonry intakes and spillways which preserve the enclosing earthen banks from damage when overflowing, but instead of insisting upon the withdrawal of water by skins in the same way as from a well, animals and people are allowed to enter and foul the water, which as a result becomes filthy.

The discovery of ground-water at a moderate depth would greatly relieve a pressing need, but the prospects are not very bright unless deep drilling is entertained. Only limestones and shales are exposed in the cliffs bordering the wadis and they are scarcely disturbed from a horizontal posture, but some water is likely to find its way underground through the medium of cracks and fissures and get held up at some unpredictable depth. The only possible source of shallow ground water lies in the alluvial deposits of the valley into which so far as could be ascertained no well has yet been sunk. The absence of any considerable catchment which would induce flushes that would scour out deep channels and leave deposits of coarse gravels and sand is a discouraging feature, still it might be worth making a trial well near the centre of the wadi below the village opposite the landing-ground. Drilling offers the best prospects, but a shaft is much easier and cheaper, and might give enough water to satisfy the needs of the R.A.F. when forced to alight here.

Naturally it is always possible to construct a cistern for the storage of rainwater with covered top from which the water would be withdrawn only by a pump. The open tanks used by the inhabitants yield only a badly-fouled water unsafe for drinking.

## WADI HADHRAMAUT

Tarim District:- The Wadi Hadhramaut forms one of the most remarkable physiographical landscape features of Arabia, and above Tarim takes the form of a broad plain of fertile silt and sand bordered by steep or vertical cliffs nearly 1,000 ft. high running in a general east-west direction for a distance of hundreds of miles. The impression gained by the sudden appearance of this great gash in the earth after hours of travel over featureless, uninhabited plateau can only be likened to a first glimpse of the Grand Canyon of the Colorada, and a visitor is almost stunned by the vista of large towns with sky-scraper buildings and palaces surrounded by broad strips of green vegetation. The rough and rather perilous descent of the 1,000 ft. cliff finds its compensations in the many views afforded of the wadi and the strings of thriving towns which line its sides. The wadi winds about in an irregular way and is fed by numerous tributaries exhibiting many of the features of the main channel. Meandering about the wide wadi beds are channels scoured by the annual floods which at intervals appear as roaring torrents after rainfall at some perhaps distant point on the higher catchment. From enquiries and observations at wells and tests with a drive tube well outfit, a fair idea of the geology of the wadi bed was obtained and it is clear that it consists of thick alluvial deposits mainly porous but not highly permeable. At some places the argillaceous (clayey) sediments are interspersed with gravels, and the whole series is likely to consist of a succession of over-lapping lenticles which include all kinds of strata ranging from compact clays to highly permeable gravels. As water is found almost everywhere at some

depth between 20' and 70' and greater depths have not been attempted, nothing is known regarding the depth of the valley sediments, but below them lie strata of Cretaceous age, the sandstones of which are likely to yield water quite freely. Through the kindness of the local Sayids we were lodged in one of the several beautiful palaces used by the rich families and it is desired to place on record our appreciation of the generous hospitality and kindly attentions received at the hands of Sayids Rahman and Bebeker Alkaf, our guide and companion on many trips.

From Tarim, a town of 20,000 inhabitants, excursions were daily made both up and down stream in order to study the hydrology of the valley, and during these journeys numerous cultivators were interviewed for information, and the depths of their wells measured. Cultivation was mainly confined to dates with an undergrowth of wheat, and near the town kitchen-garden produce was grown. Much new cultivation was noticed and the planters stated that this was the direct result of established peace and security which has recently replaced perpetual feuds, internecine warfare, plunder or extortion.

All the wells examined round Tarim were found to have static water levels within 40 ft. of the surface, and it may be that the economic range for lifting water under present conditions is between 20 and 40 ft. During spates the water-level rises in some wells, but in others far removed from flood channels the rise is reported as negligible. There is generally some fall of water-level, it is said, when abstracting water, but in some wells the recharge is immediate or the fluctuations small. According to the capacity of wells they are operated with one, two, three or even four, animal-drawn skins each of 12 to 15 gals. capacity, and from calculations made the volume raised is about 700 gals. per hour per bucket. On an 8-hour watering basis this represents 5,600 to 22,400 gals. per day, say $\frac{1}{4}$ to 1 acre-inches a day, and one single-skin well appears to suffice for about an acre of ground in the usual silt with say 7" of water a month.

No records of any kind have been kept, and the people have only the vaguest idea of the amount of water needed for various crops. Date palms are usually planted in pits excavated to a depth of 3 to 5 feet and water channels are led to these for watering at regulated intervals, but where the water-table is high the roots of date-palms soon reach damp earth, after which little artificial watering is needed. In the shade of the date-palms the farmers generally grow a crop of wheat or vegetables which obviously cannot be expected to give a high yield or produce good quality seed or fruit. We noticed such crops as wheat, millet, maize, sweet potato, beans, lucerne (alfalfa), carrots, peppers, onions, egg plant, ochroes, cabbages, spinach, and the fruits included elb, papaw, guavas, bananas, pomegranates, limes, and oranges.

A number of wells in the gardens of the rich landowners were fitted with oil-engine-driven centrifugal pumps being usually 3" with 5/6 HP motor using kerosene oil, but elsewhere no organized irrigation by pumps was seen. All the small cultivators were using men, women or both, or animals, for drawing water in skins. Sometimes donkeys, oxen, or camels would be used, and at other times mixed animals or men and animals were yoked together. The almost universal practice was to build an inclined walk down which the animals or men walked or ran when lifting the filled skins which were tilted over at the top into a trough. Over the mouth of each well was erected wooden sheer legs with a roughly-made pulley mounted at the top to carry the rope.

Near the town of Tarim a small branch valley, the Wadi Adid, with rubble floor, discharges storm-water into the town area during rains, and at its mouth in the garden of a rich Sayid a well was descended which is said to be unaffected by pumping at a rate of about 12/15,000 gals. per hour. The reason for this high capacity was manifest when the section was seen, for the sides were composed entirely of coarse permeable gravels

from which water issued freely once the water-table was depressed. Above the water-table the gravels were sufficiently cemented and compacted to hold up without any form of lining, thus exposing the full section down to 42 ft. A 5/6 HP oil-engine and a centrifugal had been installed in a chamber just above the water-level.

A scour channel of the main valley passes near the town of Tarim, and a system of canals has been arranged to conduct flood-waters about the gardens and cultivation. Where water enters the city limits or walled gardens, masonry sluices are provided which permit entry and exit of water without endangering the stability of walls through which it passes.

Proceeding up-stream the Wadi Thibi is reached, down which large volumes of flood-water enter the main valley during rains on that catchment. Here were found pools of standing surface-water, and efflorescence of salts along its bed proved that it was underlain by shallow water for some distance near the junction of the two wadis. It is said that the Wadi Thibi gives much better quality water than the main Hadhramaut stream, evidently due to passage of water over a more rocky and steeply sloping bed. A tube-well was subsequently driven to about 11 ft. in the bed of the stream near a water-pool, and gravels were encountered to about 7 ft., but after that a hard stiff clay and then a compact sand was entered through which it was found very difficult to drive, and eventually work had to be abandoned at 11 ft. A second well driven further up-stream suffered the same fate, the beds proving far too hard for drive tube well work. The surface sands and gravels were deceptive, proving to be no more than a purely local and shallow deposit lying on the harder sediments.

Crossing the broad wadi bed from north to south, miles of flat uncultivated yet fertile silts were passed with some occasional stretches of drift sand, but the latter did not form dunes and did not seem likely to constitute a menace to agricultural pursuits. Cultivation in the Western Hadhramaut is largely concentrated at the mouth of tributaries, opposite which were generally found fan-shaped expanses of rich soil prepared for basin irrigation with guiding bunds and, in some cases, well-built barrages to check scour and collect silt. All such barrages were of masonry construction and had spillways designed to carry off normal floods, for when bonded in silt a new channel is quickly scoured if they are topped, with the result that the torrent takes a new path and the whole structure is left in mid-air. Such examples were actually seen, and the neglect of such commendable and useful works was much to be deplored. Some of the side wadis were said to give a better-quality water than others - by that is meant a water with a lower percentage of salts in solution, and this is partly but not entirely attributable to differences in the nature of the catchment. Rocky areas are likely to yield a water of much lower salinity than where the run-off is from silty regions full of salts resulting from decomposition of gypseous clays. The dry-season wadi waters tend to become more highly charged with salts of lime due to concentration by evaporation where the water flows on the surface or lies at no great distance below ground. Many reaches of deeply-scoured wadi bed were damp, and due to intense evaporation in a dry hot climate were thickly encrusted with white efflorescence of salts which would later be re-dissolved and carried into the ground at other points down stream where absorption took place.

The appearance of surface flows of water and lines of pools at various points along the sandy valley at first misled one into the belief that they represented the water-table of the region, but tests with tube-wells dispelled this view, as stiff clays and indurated sandy-clay sediments that could only be pierced with the greatest difficulty were found beneath.

Up-stream of Tarim a strip of cultivation follows a low depression

closely skirting the southern cliffs of the wadi, and from the measurements of many wells and enquiries from cultivators it was gleaned that an abundance of water was available at depths between 20 and 40 ft. It was pleasing to find that beyond the older cultivation in proximity to the scarp and to the villages many new plantations had been started, due, it was said, to the greater security following the truce. Villages were numerous, near the foot of the cliffs and above flood-level, but all the larger towns were established at the mouths of tributaries where the run-off during rains could be conveniently distributed for the growing of rain crops (millet mainly). At the mouth of Wadi Tariba there is not only a big fan-shaped stretch of cultivated ground, but very effective regulation works stoutly built in masonry to check scour, retain silt, and direct run-off to the various plantations. Numbers of wells were being worked by men or animals with the water lying at a depth of around 30 ft. from the surface.

No cultivation was noticed on the north side of the valley opposite Tariba, but a trip across led us over long flat stretches of silt suitable in all respects for growing crops, where certainly water could be found at a moderate depth. Near the foot of the cliffs on the north side ran the present main flood course of the valley in a depression overgrown with tamarisk and other shrubs as well as grasses on which herds of goats were grazing. Along the scarp good sections were exposed of the geological succession showing the Eocene limestones lying upon the Cretaceous sandstones. The absence of villages and plantations on this side of the khor in this region appeared to be due to the absence of favourable sites for settlement, the danger from flood scour, and the lack of minor wadis to supplement the supply of wadi water for rain crops.

A drive tube well test was made on the south side of the valley alongside the main road to the coast before it rises up the scarp. At this point there was water running over a coarse sandy bed that appeared to offer very good prospects, but after driving in coarse, water-saturated sand to 7 ft. within a very short time hard ground was struck through which it was almost impossible to proceed, at least without damaging the apparatus. We were then informed that a new well was being sunk quite near, and on inspection it was discovered that below a surface layer of sand the strata consisted entirely of indurated sandy clay cemented by lime into a rather soft rock. Ten men were occupied in extracting water with skins to enable the diggers to work, and the water raised was thick with suspended fine sand. The excavated material came up in large chunks wedged from the side or base, and the men explained that water oozed or flowed from cracks and orifices on the well side and base. This condition was found on enquiry to be representative of the wadi conditions and deepening continued until the cultivators' requirements were reached or the influx of water prevented further work. This well provided clear proof that the surface flows represented perched water-tables distinct from the deep-seated supplies.

The well-sinkers both here and elsewhere volunteered the information that the deeper they excavated the larger the supply of water, but due to local changes in character of sediments and extent of fissuring, the capacity of wells varied considerably. Some wells, it was asserted, show a rise of the water-level during the floods, others are almost unaffected by flood or drought.

A fringe of plantations down stream of Tarim skirting the north side of the valley closely follows the course of a flood channel marked by a line of pools of water. The palm groves with their undergrowth of crops were watered by wells where the water-table lay at a depth of about 33 ft. substantially below the level of water in a nearby water-course which was doubtless perched and conceivably due to the drainage of water from well-irrigated lands. Nearby, opposite a large abandoned and ruined town, a very substantial masonry dam was seen crossing the main scour channel and fitted with wide central spillway to carry off storm-water. Up-stream

silt had collected to near spillway level, and the main object of the barrage was said to be the protection of fertile land from scour along the banks of the water-course rather than the lifting of water to a higher level for extension of flood irrigation laterally.

Our guide informed us that these barrages occurred at intervals down-stream, and whatever the real purpose of their construction may be, they do perform the task of checking scour, holding up silt and delaying the movement of water so that more percolates into the silt, and improves the moisture content. Unless given regular attention there is considerable danger of these commendable works losing their value, for we noted a dangerous scour on the southern wing wall which unless checked is sure to result in underpinning of the foundations and collapse of the structure. We were informed that they were inspected at times and repaired and this may be so, but it should be done promptly as soon as signs of damage appear.

Wandering across the valley in a southern direction from this point a depressing vista was obtained of abandoned cultivation and settlements, due no doubt to tribal conflicts and general insecurity. Over a broad area of fertile silt were seen the rotting roots of former date-palms and the channels which watered them, but due to abandonment rain scours had caused such destructive erosion of the soft silts that the whole district was so cut up with miniature ravines that even foot movements were rendered quite difficult. Obviously at one time water was available here and could be made so again.

## SEIYUN

After a few busy days at Tarim, when a thorough inspection of the neighbourhood was made, we proceeded up-stream to Seiyun, another large town on the south side of the Hadhramaut valley, and from that town excursions were daily undertaken to all neighbouring points of interest. Between Tarim and Seiyun many towns and villages were passed around which palm-groves were numerous with an undergrowth of healthy wheat and a sprinkling of other crops, but it was noticeable that the larger townships were always located at the mouth of subsidiary wadis where all surface run-off could be deflected to cultivable areas in the rainy season. Around every town scenes of lively activity were witnessed where fields were being irrigated by well-water drawn by human or animal labour or a combination: sometimes even by women and children harnessed to a rope. Now and again groves of tall palms where the roots had been able to reach water or damp earth, no longer required perennial watering relying entirely upon the annual flood. Elsewhere extensive areas of abandoned palms were passed marked only by a secondary growth of attractive but useless suckers around the dead stump of the parent tree obviously relics of past endeavours. Seiyun itself nestles in the midst of a thickly-cultivated area on the edge of a broad tributary wadi with stony bed which must during rains carry very considerable volumes of water to the many gardens around the town and suburbs. Flow-channels with sluices beneath the partitioning walls of compounds give some idea of the extent to which such water is used when available, but this is quite subsidiary to the main service of irrigation by wells which are everywhere in evidence. The well in the grounds of the villa of Sayid Bebekir, where we were hospitably housed, was 60 ft. deep with about 24 ft. of water, and it was equipped with a 3" centrifugal pump and oil-engine throwing about 12/15,000 G.H. At this rate of abstraction the water-level fell rapidly and two hours were needed, it was said, for its recovery.

By a rather tedious process of cross-examination the following facts were elicited from an interview with two well-sinkers who said they had excavated about fifty wells in the district. No well had failed to yield water but at times the sinkers had encountered rock too hard to continue, and they had to rest content with low yields and a small depth of water. They insisted that the supply invariably increased with depth, and stated that incoming water issued in squirts and jets from cracks, fissures and orifices in the strata, as might be expected, rather than as a uniform

oozing from the sides. Wells were generally lined throughout with cobbles or uncemented masonry, but lining was only essential where the sides were composed of silt which when damp readily crumbled. Some wells like that in the villa garden required no lining as the sides were in compact strata from the surface and required no support. The men stated that all wells in the district drew their supplies of water from indurated beds (sandy-clays) and not from gravels and, whilst working, water had to be kept under by bailing so that in case of a free-yielding well as many as twenty men were occupied in water removal. Until water was struck, five to seven men were engaged at the well, and the rate of progress for a normal diameter well of 6 to 8 ft. was between $1\frac{1}{2}$ and 4 ft. a day. The pay was given as $\$\frac{1}{2}$ per day for headmen and $\$1/3$ per day for others, together with something in the neighbourhood of 1 lb. of dates per man-day. They sometimes blasted with gunpowder, but customarily a bar for wedging and an adze kind of weapon for scooping were the implements used.

The workmanship at wells inspected was generally good, and the quantity of moss and ferns sprouting from the loosely-packed masonry surround could be taken as some measure of their permanence. Over the top were spread logs of untrimmed palm trunks, and the tripods used to support the overhead pulleys were made of split palm trunks. The above description appears to apply to most wells in the country, but where engines and pumps are installed an inclined staircase had usually been excavated to a space just above the water-level and here the plant was installed. On remarking upon the danger of asphyxiation by exhaust gases of the engine which were not usually led to the surface by a pipe, they said that men did get gassed or killed sometimes, but this apparently did not justify the expense of an exhaust pipe to the top of the well.

In the Wadi Jaza some distance down-stream of Seiyun we were shown the ruins of an aqueduct which once carried the effluent of a spring to cultivation in the plains. The wadi itself is quite a minor feature compared with most, and a fan of very coarse gravel and boulders marked its emergence into the plain. Proceeding up the rocky bed, one soon reached a narrow boulder-strewn gorge into which had fallen huge masses of limestone from the bordering cliffs which rose abruptly on each side. Some of the detached blocks were of gigantic proportions and rectangular in shape, measuring perhaps 20 ft. across their sides, and in falling they had entirely demolished and buried the little open, rectangular, masonry aqueduct which contoured the wadi side on a steep gradient. The source of the spring was marked by a succession of pools of clear water held up by accumulations of detritus from the hills, and the final showings of water were in a highly cellular limestone resting on a more crystalline bed. This was above the limestone-sandstone junction here obscured by banks of limestone scree, but the site was probably not far above the junction.

No particular difficulties would be found in repairing the damage and restoring the supply if it were thought worth while, but the yield is evidently inconsiderable and unlikely to do more than irrigate a small patch of gardens in the plains. Where the gorge has been choked with boulders a new alignment would be necessary and some blasting might have to be undertaken to remove obstructions. This visit to the spring was illuminating in showing the kind of conditions that probably occur in most of the wadis where, however, the water issues are nearly always concealed by deep coarse boulder beds which encumber the upper parts of branch wadis near the junction of the limestone and sandstone.

Faced with so many conflicting explanations for neglected and abandoned plantations, it was quite impossible to form any intelligent conclusions as to the cause. Such reasons as the death of an enterprising planter, warfare and feuds with consequent insecurity, scarcity of labour, fluctuating price of produce, unsuitability of land, or unsatisfactory quality of well waters were made, and part or all might conceivably have had some bearing on the economics of the situation. Mr. Hartley, however, was convinced that it was inconceivable that such large areas as seen would have been planted had the soils or waters been unsuitable, for the decaying stumps of thousands of fully-grown date-palms were found on ground now only strewn with suckers that had survived without artificial watering.

On paying a second visit to an area of land near Seiyun where it was proposed to establish an experimental agricultural farm, a more extended and detailed examination of the ground led to a discovery which may account for many of the abandoned palm-groves. Below a superficial layer of silt was found a hard calcareous pan some few inches thick through which water could not percolate nor roots pierce: indeed, an excavation was discovered by chance where the cramped roots of palms were seen running horizontally over the surface of this hard incrustation which they could not penetrate. Nevertheless a cultivator was found busily replanting a discarded area, and on interrogation he volunteered the information that if the pan was broken and the palms planted so that the roots could enter the underlying softer ground, they flourished. It may be that this is the main reason for much of the stunted date-palm plantations seen, where, after a time the soil soured from lack of drainage, and tap-root development was impeded or entirely checked. It may also provide an explanation for the patches of puffy earth with efflorescent salts occasioned by capillary evaporation of water which cannot drain away with consequent concentration of salts.

Such lands could obviously be avoided. but if needed the most satisfactory method of planting would be to use explosives in all excavations made for palms so that cracks for root expansion could be formed as well as channels for drainage, besides reducing labour by loosening the earth prior to excavation. This is a method largely followed today in U.S.A. and materially accelerates the growth of new plants. Land of this description could be reclaimed by the simple expedient of carrying trenches or pits through the pan to allow drainage into the underlying beds.

The value of power-pumping was illustrated by the condition of the beautiful garden that surrounds the villa of Sayid Bebeker, but such installations are probably beyond the financial resources of most planters, and the old system of animal water raising may suit the people best. There are no signs of water scarcity for almost everywhere water could be obtained at depths up to 50 ft.

## SHIBAM AND DISTRICT

Travelling up-stream from Seiyun along the southern edge of the valley, many more well-built towns and villages were passed, around which were concentrated palm-groves and plantations of wheat and alfalfa with a sprinkling of mixed produce. Every wadi of any practicable dimensions was provided with bunds and training walls for directing the flood to prepared basins where the ground had often been ploughed and weeded ready for planting. Sometimes land had been prepared for planting far out into the plain in anticipation of a possible spate which would spread water far afield. Patches of new cultivation were everywhere in evidence and a number of wells were seen in course of construction for the purpose of irrigating new farms. The measured water-level in the wells fluctuated around 40 ft., a depth which does not appear to cause the cultivators serious concern. The sight of so much activity was a source of considerable gratification to Mr. Ingrams and a remarkable contrast with past observations.

At Shibam itself, water occurs at the shallow depth of 6 ft, in the depression on the south of the city walls. This flood-course separates the valley banks from the remarkable cluster of tall dwellings rising like an excrescence from ground where it seems so out of place. The quality of the water was described as bad, which is not surprising considering that much of the town drainage finds its way into this depression not far from the main gateway facing the wells. Within the town there are numerous deep wells said to yield a better water than those in the river-bed to the south. Shibam seems an outstanding case where some form of piped water supply would prove a boon to the inhabitants, and where at no great expense pure clean water could be pumped from wells outside the town to central distributing stations.

When crossing the Wadi from south to north to Qazal-al-Azziz some remarkably fine palm-groves and wheat fields aroused astonishment and admiration, for the stalks had attained a degree of growth that compared favourably with the best cornfields of England, although relying solely upon irrigation by water raised from a depth of no less than 50 ft. by bullock, camels, men and women from wells of 5-skin capacity, say nearly 3,000 G.H. The water had a distinct though not objectionable taste. Exaggerated claims for yield were made by interested parties, but Mr. Hartley considered one ton per acre as likely for such robust, healthy, pest-free crops - a truly gladdening sight in a sea of barren silt.

Up-stream some miles, opposite the Wadi Ser, a long masonry directing wall has been built to deflect the flood waters from the southern banks towards the centre of the valley. This guiding wall, which is substantially constructed, skilfully designed and well-bonded to the southern cliffs, was said to have been built in order to protect Shibam from damage during violent spates. Although an ancient structure, it is apparently kept in a state of repair by the Shibam authorities, as the danger of a big uncontrolled flood to the town is very real. Still skirting the south bank of the valley, many villages were passed where fields of green wheat were being irrigated by well-water, and at one place the sloping, rocky, southern sides of the wadi were stacked with bundles of dura stalks, the residue of flood crops which had been harvested during the last season. This unusual sight of unprotected, stored goods was regarded by Mr. Ingrams as a very definite sign both of prosperity and of faith in the prolongation of peace.

A break was made at Al Qatan to call on the Sultan at his palace, and after tea and a chat he conducted us to gardens and plantations near his residence. He maintained that at least three crops annually could be taken from land in the district by suitable rotation. Water was being lifted 36 ft. from wells and there were several power-plants with 3" centrifugals operating in the district. One estate was fitted with a 15 HP electric generating set for pumping three separate wells, but the installation had been neglected and fallen into disrepair so that it was now only able to pump one well, a very costly process. The Sultan maintained that many new wells had been sunk in recent times as a direct consequence of the more peaceful conditions.

Deviating southwards from the Western Hadhramaut into Wadi Kasr, there was a noticeable decline of present-day cultivation, although villages lined both banks, and a strip of healthy elb trees and other hardy shrubs marked the main course of the Wadi Kasr which extends south-west to Douan. Entering the Wadi Ahmed, striking examples of past prosperity were manifested by the piles of silt lining former canals or surrounding basins in which flood crops had once been grown. So dense and intricate was the system that it was no easy matter for the car to wind its way around, between or over the banks which encumbered the ground in all directions. Date-palms were scarce due, it was explained, to the ferocious ravages of revengeful tribes who raided and destroyed each other's farms, even going to the extent of employing kerosene consigned at great expense solely for the purpose of firing palm-groves. The desolation observed was the result of this relentless and senseless warfare.

From this wadi a turn was made into the Wadi Nisen where a string of sporadic palms marked the course of directed flood-waters along a canal system, but perennial cultivation ceased in this direction due to the gradual deepening of the water-table which sank by degrees to beyond 100 ft. On reaching Hureighda, a town of considerable size and importance where we were hospitably accommodated by a talented Sayid, Ali-al-Attas, it was found that the population depended entirely for their dry-season supplies of water on a number of wells about 250 ft. deep. This depth precluded the employment of ground-water for irrigation, and there are therefore no gardens nor is wheat grown in the district. The many healthy date-palms are nurtured to maturity by hand-watering from wells at intervals of 40 days for a year until the roots reach a depth which supports them over the periods between successive floods. Many of the

trees were probably 20 to 30 years old, and had survived several crisis years when no rain fell, but the older trees were confined to deep basins where the annual accumulations of silt had enforced its removal by hand to the surrounding bunds, or the palms would have been smothered and the ground raised above canal level. So great has been the amount of silt removed in the neighbourhood of the junction of the wadis Ahmed and Nisan that the piled-up silt mounds reach a height of nearly 100 ft. to the top of which it continues to be carried and deposited by men or animals. The canal system still functions at about the original level as the off-takes of the main wadi channel admit of no heightening of their bottoms. From the summit of these hills a splendid view is obtained of the cultivation and its orientation with reference to the scour channel of the Ahmed and the flanking dura fields which were in process of being ploughed.

Whilst at Hureighda, visits were paid to three springs alleged to have yielded at one time considerable quantities of water, but these legendary accounts must be accepted with caution although some support for such a contention was not lacking though it may have anti-dated human occupation. Access to the springs entailed a fatiguing climb by a steep, winding rocky track up the cliff face, and they proved to be seepages of very cold water from cracks and orifices in the limestone close to its junction with the sandstone. That above the village of Sharef al-Kishmin was giving a steady flow of water from a crack lined with precipitated lime, maiden-hair fern and moss, and the effluent collected in a muddy pool from which it was scooped by cups into skins and carried by donkeys to the palm-groves in the valley. The output was given as 300 gals. a day, but it had the appearance of more than that and was said to be incessant, although when rains fell the yield increased. The sandstones below the spring were deeply and brilliantly stained in tints of red, pink, yellow, purple and violet, indicative of contact with ferruginous waters, and the remains of a masonry aqueduct lent some support to the view that at one time the discharge was greater. It was also noticeable that some of the limestones were cellular (possibly dolomitic) and heavily veined and studded with calcite crystals due to re-precipitation of carbonate of lime after solution. Such a small discharge does not warrant expenditure on any scheme of distribution, but the conditions appear to justify the construction of a lined tank into which the water can collect prior to its removal in skins. The surroundings are now filthy.

The second spring nearer the town, but at about the same altitude, proved to be no more than a few trickles of delightfully cold water from fern-lined cracks in the limestone where it made contact with the sandstone, but numerous calcite-lined orifices in the face of the cliff indicated former points of issue, probably during rains. The water dripped from an overhanging rock, above which was a most impressive vertical cliff of banded limestone, whilst below lay littered about the slopes immense blocks of fallen limestone so regularly shaped that they might have been fashioned by stonemasons.

The third spring was Al Hadhadh on the south-west side of a minor wadi leading from the Western Ahmed a few miles up stream of the Western Nisan and nearly opposite the Hamaritio excavations where the Misses Freya Stark and Caton Thompson worked. The spot was reached after $1\frac{1}{2}$ hours walk from Hureighda, and the cliff ascent was exceedingly rough and steep after a long trail over rubble-covered talus. From the foot of a vertical face of limestone trickled a few dribbles of cold water from cracks along fern-covered runnels to pans built for its reception, the overflow, if any, succouring a few figs and a single date-palm which sprouted from boulders below. The remains of a small, lined masonry aqueduct steeply descending to a cleared spot below are still visible although no water now passes, but so small a supply scarcely deserves much attention unless excavations round the springs and protection from seepage losses led to a great improvement. The popular view that the orifices are choked cannot be confirmed, for if one became plugged water could break out quite easily elsewhere. The calcite deposited in the holes doubtless represents the final stage when evaporation just about coincided with the rate of efflux.

Of considerably greater interest was the fact that the cellular limestone immediately overlay a schisty bed of dark-coloured shale resembling an oil-shale, the contact zone being characterized at the outcrop by a striking white flocculent efflorescence of salts which were collected for analysis. One specimen had a distinct NaCl taste but others were less acrid, and it was difficult to judge by the tongue of their composition. The anticipated sandstones were not actually seen at the site so that their stratigraphic relationship could not be determined, but they were found a little lower so that it seems safe to assume that they constitute transition and are the upper part of the Cretaceous group.

## DU'AN

During a flight from Hureighda up the Wadi Ahmd and across the plateau to Du'an a wonderful panorama was disclosed of the tableland topography and its dissection by gorges, which, originating from a mere surface irregularity developed into narrow canyons with vertical sides almost within a few yards. In the bottom of the deepest wadis would be seen strips of vegetation along dry water-courses with occasionally fringing stretches of ploughed land cut into squares for planting were plainly visible. The horizontality of the plateau strata was brought into strong relief by the lighter streaks surrounding the odd chunks of tableland scattered over the country. Black patches denoted accumulations of the iron-stained flints or ferruginous concretions which weather out of the limestones of some horizons. Caravan tracks were outlined by whitish streaks twisting about the ground, to dodge ravines, and the Wadi Du'an presented a remarkable sight when the narrow 1,000 ft. defile was crossed and recrossed by the 'plane.

The descent into the Wadi Du'an is by a perilously steep pathway cut into the 1,000 ft. cliff which borders this narrow gorge, and from points of vantage during the hot, tiresome journey, magnificent views were obtained of the wadi bed and its line of towns and string of palm-groves. Long before the base was reached the sandstone junction was passed, and a display of variegated sands and limestone boulders clearly showed the whereabouts of a one-time spring where a big slide had occurred. Along the valley which only carries water in the rains are terrace strips of silt ploughed ready for dura planting when the rains fall.

Visitations to numerous wells and springs up and down stream of the Governor's castle of Masna'a, and many talks with the ruling Ba - Surra family and local notables, enabled us to obtain enough data to form a reasonably clear conception of the water problem of Du'an. Quite a number of springs are known and the effluent of even the meanest is used for domestic or garden purposes. Those seen were all small issues from one or more crannies in the base of the cliff near or below the limestone and sandstone junction, and those at lower altitudes were very obviously due to the re-issue of water derived from higher sources in steep boulder-strewn gullies with which the cliffs are indented. At each a tank had been built for the accumulation of water during the night when not otherwise used and from these receptacles masonry runnels were led to gardens or cultivation. The best spring seen was that of Ghuwala near the town of Al Qurein where a flow of 100 G.H. was measured. Donkeys were employed for the cartage of water in 4-gallon skins to the houses below, and little could be suggested to improve existing arrangements except a general clear-up of the area and the more careful conduct of such water as is available to the receptacles. No substantial improvement is likely to follow the opening-up of the springs and there is just the chance of losing the supply by breaking into a fissure.

Each town along the valley relies mainly upon wells for domestic needs, but the depth to water lies between 150 and 300 ft. according to the location with regard to the wadi floor. So valuable is the land that nothing is permitted which would impair the utility of silt-bearing land

capable of being brought within the influence of floods or hill-side run-off. The valley wells give very variable yields, some being reported to be unaffected by the maximum rate of extraction and to be uninfluenced by rains or floods, but so far as could be ascertained, the maximum amount taken from a single well is about 2,000 gals. a day so that past extraction cannot be regarded as a reliable index of capacity to yield. As found elsewhere in the Hadhramaut, the well-waters are not cold but about 70°F., although in this respect there appears to be some differences. Unlike Hureighda, the spring-waters were not cold, indicative of some shallow travel after emergence from the real source.

Land values in the Du'an valley are amazingly high, some £50,000 per acre being named by our hosts as a fair valuation, since single palm-trees of medium full-bearing age find willing purchasers at ℔300 to ℔500. Crop values of date-palms are given as ℔40 to ℔100 per tree for the four to twenty bunches they annually bear; so on the basis of 700 trees per acre, an acre of date-palms may yield ℔28,000 to ℔70,000 a year. With such values it is surprising that any land is left for dura plantation, but the dwellers of the valley desire to be self-supporting whatever the sacrifice involved, and as the landowners are all wealthy men who have amassed riches abroad they can afford to be independent.

If the facts are as related, the people possess ample means to sink wells and to pump water for perrennial irrigation of gardens, for at present practically no fruits or vegetables are grown and cultivation is confined to dates and dura. Near the Fort of Masna'a, where we were luxuriously housed by the joint Governors, water was obtained at 150 ft. At Al Quarain a well was plumbed at 175 ft., but the people draw much of their water from a spring, Ghurwala, near the face of the scarp, which gauged about 100 gals. per hour. Water is collected in skins and carried by donkeys to the households, but at very little expense it would be possible to lead the supply of pipe-line to the town, where a tank and public fountain could be installed. The distance is about 400 yards and there is ample head to ensure a gravity flow in a $1\frac{1}{2}$" diameter pipe: sufficient storage should be furnished either at the spring or in the town to conserve the night supply.

Above the Fort at Masna'a the effluent of a spring is conducted by a winding aqueduct to the Fort, entailing a most intricate construction over a rugged cliff face during a descent of some hundreds of feet. Proceeding up-stream from Masna'a the wells become deeper, and at Rashid we found one 240 ft. deep. At Al Khureiba, a large market-town, a well measured 162 ft. At Rashid we saw the people engaged on the construction of a second tank in the rocky wadi bed designed to collect and conserve flood-water. One rock tank already in existence with a capacity of about 300,000 gallons was irregular in shape, fully 30 ft. deep, lined with cement grout for water tightness, and so arranged with regard to the flood-channel that silt and debris could be trapped. The cost was given as ℔2,000.

Wells sunk in the Du'an wadi all penetrate Cretaceous beds in which sandstones predominate, and it is strange that the water-table is so low. Many of the sands are coarse in grain and very suitable aquifers, and the high permeability of some layers may be the reason for the poor yield of wells due to rapid down stream drainage of water towards the Wadi Hadhramaut into which the Du'an discharges at a much lower level. At Al Kureiba a well-sinker was interviewed, and from him it was ascertained that the valley alluvials are everywhere shallow, then follow red and white sandstones with clay bands and low down black stone (basalt ?) beneath which water is often found. Water sometimes occurs under a pressure head and rises some distance when struck, and it usually issues from crevices and orifices in the sides. The larger the fissures the greater the yield of water. As much as 6 ft. a day can be excavated at top, but later only 2 to 3 ft. a day, and it may take twelve months to complete a well. Labour is paid at the rate of ℔$\frac{1}{2}$ a day plus food, and the wells are said to cost from ℔2,000 to ℔2,500 each. Water is always

warm and the heat is described as excessive whilst working. Work is stopped when water is struck as they fear losing the supply by going deeper. The salinity varies somewhat in different wells, but is always within potable limits and likely to be bacteriologically pure until handled by the people.

A desire was expressed for a piped scheme of water supply for some five towns in the wadi with 12,000 inhabitants and 6,000 animals, say about 60,000 gallons a day or 5,000 G.H. on a 12-hour pumping basis for the dry part of the year. Such a supply, although large, should not be beyond the capacity of a well carried to a desirable depth with headings to give adequate infiltration area. The power involved would be of the order of 12 HP and the plant would cost about £580 C.I.F. A well might cost about £300, and the piping to various villages would be, for 4" mains, about £620 per mile.

All depends upon adequate water being found, but such a community should be able to afford a test with a light mechanical drill when success would make such an enormous difference to the welfare of the valley inhabitants. For test purposes a hole might be bored in the bottom of an existing well without endangering the existing supply or interfering with present work of the well. Although progress would be slow, a hand-rig could be used to avoid the great expense of transporting heavy machinery. In any case, the conditions warrant a test for deeper water which is likely to be under a pressure and rise at least to the level of water in existing wells.

## ABR WELLS

During a flight from Du'an to Abr wells a further bird's-eye view of the great Du'an gorge was obtained following which the fertile upper reaches of the wadi Ahmed with its chain of villages and long strips of palm-groves and ploughed land came in sight. The wide western end of the Wadi Hadhramaut appeared from the air to be an almost unending wilderness of drift-sand partly obscured by a cloud of dust and sand which was raised by a stiff wind near the ground. Passing high over plateau country cut up into a mosaic pattern by the many canyons, one remarked upon the numerous patches of black flints which could easily be mistaken for oil seepages at the height we were flying, and one could follow quite easily the outcrop of single light and dark coloured strata which surrounded all the table-lands and skirted surface configurations.

So black was the rugged surface of the ground near Abr wells that one was at first misled into believing that the rocks were basaltic in character, whereas the darkness was entirely due to a surface litter of iron-stained fragments of sandstones and limestones.

From the landing-ground it was a walk of about two hours to the fort over wind-swept, rock-strewn country dotted with much disturbed and shattered limestones and sandstones. Flint flakes simulating stone-age implements and remarkable nodular concretionary, siliceous fragments, were scattered in such profusion over the ground as almost to deceive one regarding their origin. At the wells the fort was found to be built upon a sandstone bluff which bordered a broad, flat wadi with sandy bed thickly bordered with acacias. In the distance one saw limestone-capped hills on the sides of which an indescribable confusion of loose, huge boulders and scree simulated in appearance a traditional rubbish heap.

A plentiful supply of good quality water is obtainable from several wells sunk into the wadi bed below the fort, and it issued from a sandstone underlying some 10 ft. or more of loose coarse sand which has to be supported by a lining. The yield is said to be unfailing and abundant and during the rains the level rises to near the surface. Visited from antiquity by travellers, it is described as the only permanent source of water on one of the main caravan routes between the Yemen and the coast, and in consequence has great strategic importance. On the face of the rock opposite the wells are markings and drawings which to the initiated

fix the spot where wells can be re-opened if destroyed accidentally by flood or intentionally by enemies.

An examination of the wadi banks disclosed the existence of much false-bedded sandstone of variegated colours with interbedded seams of very coarse gravelly sand and bands of the curious silicious nodular concretions such as litter the country side. The strata are ideal as water reservoirs, and if they extend, as is probable, to some moderate depth below the river bed, very large and sustained supplies of water could be obtained not only for travellers and animals but for irrigation of land on the wadi edges. Mr. Hartley felt satisfied suitable ground could be located to grow produce for the garrison and supplies for sale to passing caravans.

At little expense large volumes of water could be made available for farms or for pastoralists, and windmills would work admirably so long as there was wind. Tube-wells and hand-pumps could be installed for the use of the garrison and others and be so arranged that they would suffer no damage during floods.

## BALKOF

Flying from Abr wells to Balkof, a village on the coast, one saw during the journey a strange transformation of scenery and geology and experienced new meteriological conditions. After passing miles of country swept by drift sand and the important Wadi Hajr lined with villages and cultivation, a belt of clouds was reached caused by condensation of moist sea air, and a severe buffeting was administered whilst passing in and out of clouds over land cut up into a perfect maze of sharp peaks through which it appeared difficult to find a goat track. As the coast was approached, sheets of basaltic lava came into sight and could be distinctly traced out to sea. The landing was made some miles from the port near to a wadi with sides thickly overgrown with healthy acacias, tamarisks and other trees, so evidently carrying water at no great depth.

About one hour's walk along the coast led to the little fishing village and customs port of Balkof which is dependent for water upon dhow carriage from the before-mentioned wadi. First, saline flats with moist puffy earth at about sea-level were crossed, then a basaltic hill was reached, after which the route was over basaltic rocks until the village was entered. Except for small embayments enclosing raised coral beaches cemented into a conglomerate, the coast line was exclusively built of black basalt, reefs of which extended out to sea.

A somewhat hasty survey of the country in the vicinity of the town led to rather discouraging conclusions regarding the development of a local water-supply. Apart from one of the little inlets breached by the sea where a superficially raised beach built of coral debris and fragmentary shells overlay the lava bed, nothing but basalt was found. This in itself does not preclude the possibility of ground-water as the lava is often highly visicular, decomposes readily, and is frequently laminated and broken by old land surface following intermittent flows when atmospheric decomposition has given to them sufficient porosity to form valuable reservoirs for water. A few wells have been sunk to about 20 ft. in the basalt without striking water or meeting any noticeable breaks or even cracks such as would serve as reservoirs, and we saw nothing to suggest the occurrence of porous seams. The raised beaches are very suitable reservoir rocks, but unfortunately they are so thin and so restricted in distribution and dimensions that they are valueless as potential sources of water. The villagers have made a few cisterns for the storage of rain-water, but the supply does not last long after the rains have ceased.

Whilst we would not absolutely preclude the idea that the lavas contained potable water without deeper well-sinking or drilling, we regard the prospects as distinctly unpromising and we would prefer that some

scheme be considered for pumping water from the wadi near the aerodrome, should it not be found possible to locate potable water nearer on the flats before the first hill of lava is met. There is just a sporting chance that drinkable water might be found near the hills where surface run-off would partially or entirely replace the salty water almost sure to be met on the flats nearer the sea. As shallow excavations would prove or disprove its occurrence, a trial seems warranted before entertaining a more distant source: a site should be chosen near where a gulley discharges into the flats because at such places the alluvials are likely to be more permeable and their water contents more frequently refreshed by new additions.

Should it be felt undesirable to pump water several miles, the question of tanks is worth considering, as the run-off from the bare clean basalts would be very pure, and if collected in covered tanks provided with a pump for extraction the water would remain good for a long time. An allowance of 5 gallons per head per day for the population should reasonably satisfy local domestic needs.

## PLANT AND STAFF

No little difficulty is found in recommending a policy of water development in a country where there are few roads and poor transport facilities, the labour is untrained and restless and caste distinctions impose hindrances. The use of mechanical devices in such a wild country introduces many problems which one knows from experience elsewhere will cause vexacious delays when spares cannot be obtained or damage repaired without long waits. Fuel and water needs for mechanical drilling rigs often entail considerable expense, and carefully organized transport to keep the machinery working is a necessity, for one serious breakdown may cause a long period of enforced idleness. For such reasons as the foregoing we advise the employment as far as possible of simple methods which can be practised by the people themselves under the guidance of Europeans.

Except in a few localities the prospects of striking deep-seated water of potable quality is distinctly unpromising, and although a deep test would afford valuable information, we feel constrained to recommend that the early drilling should be confined to shallow borings not deeper than say 300/400 ft. By confining operations to this maximum, the rig could be made sufficiently portable to admit of transport almost anywhere within the Protectorates. Such a rig could be used for drilling at Mukalla, along the coastal plains, and eventually the Wadis Hadhramaut and Du'an.

We also advise the engagement of a qualified well-sinker who could dig and line wells and instruct the people in the art of scientific well-sinking. The man appointed should be provided with tools and appliances for excavation and with explosives and firing mechanism for exploding charges. Once local men are trained, a single European could supervise the construction of a number of wells within comfortable range of some established camp.

In order to assist such work and to make adequate tests of any water encountered, we advise the purchase of three test pumps of a capacity of 5,000 to 18,000 gallons per hour. By their use, operating could be continued in the dry season far below the water-table, thus allowing for some considerable fall of water-table. When the wells exceed 25 ft. in depth it will be necessary to lower the pumps in a side chamber.

The employment of deep well pumps is not advocated as their withdrawal for repairs or replacement of cup leathers or valves involves operations liable to lead to serious accidents. The objections would apply with less force to machinery within easy reach of a town like Mukalla.

As an auxiliary to other methods, windmills could be used with advantage in localities where the water is not deep. When there was insufficient wind to run the mills, water could be raised by human beings or animals through the medium of skins or by a chain or bucket pump.

A. BEEBY THOMPSON & PARTNERS

# APPENDIX

## EASTERN PROTECTORATE

| Total lift in feet | 10 | 20 | 40 | 60 |
|---|---|---|---|---|
| 5,000 gals. hr. (about 5-acre inches a day) | | | | |
| H.P. required | 0.5 | 1.0 | 2.0 | 3.0 |
| Cost - Engine and Pump | | | £90 | £90 |
| Fuel, gallons per day | 1 | 2 | 2.7 | 4 |
| 10,000 gals. hr. (about 10-acre inches a day) | | | | |
| H.P. required | 1.0 | 2.0 | 4.0 | 6.0 |
| Cost - Engine and Pump | | £90 | £90 | £105 |
| Fuel, gallons per day | 2 | 3 | 5 | 8 |
| 15,000 gals. hr. (about 15-acre inches a day) | | | | |
| H.P. required | 1.5 | 3.0 | 6.0 | 9.0 |
| Cost, Engine and Pump | | £90 | £105 | £130 |
| Fuel, gallons per day | 2.5 | 4 | 8 | 12 |
| 20,000 gals. hr. (about 20-acre inches a day) | | | | |
| H.P. required | 2.0 | 4.0 | 8.0 | 12.0 |
| Cost, Engine and Pump | | £90 | £130 | £160 |
| Fuel, gallons per day | 3 | 5 | 10 | 15 |

---

Diesel oil is likely to cost at distant points about 1/- per gallon or about 6d. per gallon in Aden.

Crops may take from 3" to 6" of water per month according to the produce grown and the season of the year.

The fuel consumed per acre irrigated would vary approximately as follows according to the size of plant:-

Fuel required for 3 acre-inch watering:-

| 5,000 gals. hour plant | | 20,000 gals. hour plant | |
|---|---|---|---|
| 10' lift | .6 gals. | 10' lift | .45 gals. |
| 60' " | 2.4 " | 60' " | 2.25 " |

Some additional small outlay for lubricating oil and stores would be necessary.

"CLIMAX" Windmills: Duties on basis of 12 miles per hour wind.

12 ft. Mill on 30 ft. tower:

| Lift in feet | Low | 25 | 50 | 100 |
|---|---|---|---|---|
| Gallons per hour | 3,000 | 1,450 | 570 | 400 |
| Approx: acre-inches water per day | 3.1 | 1.5 | .59 | .41 |

Cost £45. plus pump and tubing according to size and depth.

14 ft. Mill on 30 ft. tower:

| Lift in feet | Low | 25 | 50 | 100 |
|---|---|---|---|---|
| Gallons per hour | 5,500 | 3,000 | 1,400 | 650 |
| Approx: acre-inches water per day | 5.7 | 3.1 | 1.4 | .67 |

Cost £55. plus pump and tubing according to size and depth.

---

END